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TRADE-OFFS IN DESIGN OF HIGH-SPEED PERMANENT MAGNET GENERATORS FOR MICRO GAS TURBINES

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Abstract. High-speed electrical machines are widely used nowadays, in variety of applications. New technologies and development in the field of materials and power electronics enable constant increase in rotational speeds, which keeps high-speed machines in the focus of scientific and industrial interest. In this paper some trade-offs in design of high-speed generators which are used in micro turbine applications are considered.

Keywords: high-speed permanent magnet machines, inductance, slotted stator, windings.

INTRODUCTION

Needs for high-speed electrical machines have increased significantly in recent decades. High-speed machines are used in number of applications, such as more-electric engines in automotive industry, flywheel energy storage systems, high speed spindle applications, turbomolecular pumps, gas compressor applications and micro gas turbines [1].

Induction machines, switched reluctance machines and permanent magnet (PM) machines are mostly suitable for use in high-speed applications [2], [3]. Although induction machines have very robust construction suitable for high-speed operation, existence of rotor currents influences their efficiency, which is very important in high-speed applications. Switched reluctance machines, on the other hand, have very suitable rotor construction for high-speed operation, without windings and mechanically vulnerable parts such permanent magnets. However, due to large air-gap they require high excitation currents which also decrease overall efficiency [3]. Despite some limitations and drawbacks PM machines are most widely used in high-speed applications, especially for speeds above 100.000 rpm [4]. This paper tends to discuss the most significant features of high-speed PM machines used in micro gas turbine applications and design trade-offs.

STATOR TOPOLOGIES OF HIGH-SPEED PM MACHINES

According to stator geometry design, PM machines can be divided into slotted and slotless. From the manufacturing point of view, slotless machines are easier to produce, especially for small volumes, because there is no need for inserting windings into slots and production of stator core is simpler. Slotless machines, due to their higher effective air gap and consequently lower flux density [3] are considered to have lower power density than slotted machines. This makes slotted machines as a primary choice in applications where high power density is required. Energy applications, such as micro combined heat and power (CHP) systems which use high-speed PM machines coupled with micro gas turbines, represent typical energy application which requires high power density.

Smaller effective air gap and existence of slots in slotted machines result in higher rotor losses when compared to slotless machines. Smaller effective air gap causes higher armature reaction field [2] and consequently higher losses as a consequence of time harmonics in stator currents [5] and spatial harmonics in winding distribution [6]. Existence of slots causes additional rotor losses due to permeance variation [7]. Therefore, a significant drawback of use of slotted machines instead of slotted is higher risk of magnet demagnetization.

WINDING TOPOLOGIES: TRADE-OFFS

Two main winding topologies used in slotted PM machines are overlapping (distributed) and non-overlapping (concentrated) windings, as shown in Figure 1. Use of non-overlapping windings makes machine production easier and less time consuming. Furthermore, due to shorter end windings non-overlapping topology facilitates lower Joule losses and less leakage flux.

However, as already mentioned in the previous chapter, rotor losses are highly dependent on spatial harmonics in winding distribution. As a consequence of that, significantly higher rotor losses are present in the case of concentrated windings. As a test case for comparison of rotor losses in machines with different winding topologies (concentrated and distributed) 2 slotted high-speed PM generators used in a micro CHP application will be considered in the full paper. The generators are directly coupled with a micro gas turbine in a system with nominal speed of 240.000 rpm and target output power of 3,7 kW.

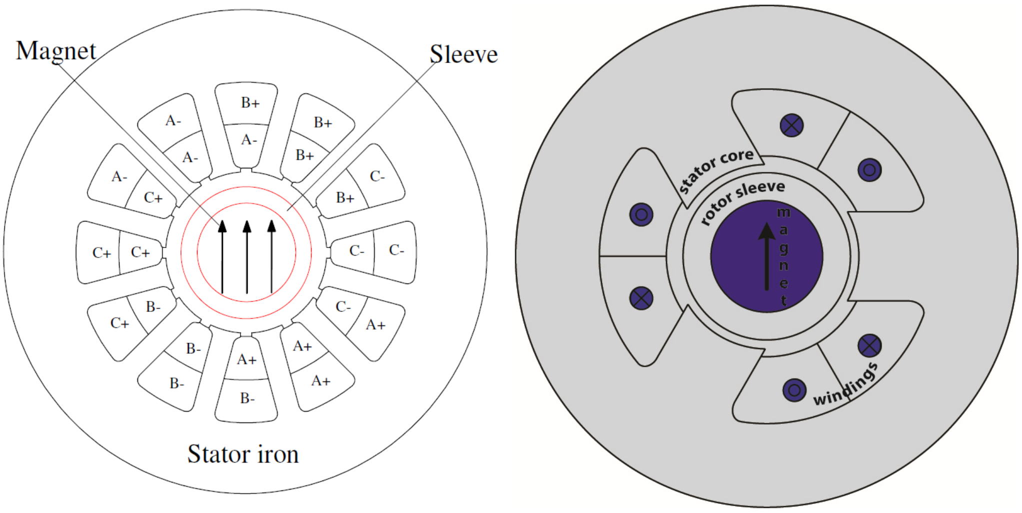

Figure 1. PM generators with distributed (left) and concentrated (right) windings.

INDUCTANCE OF HIGH-SPEED PM MACHINES

One of the typical properties of high-speed PM machines is low inductance. Machines without iron shaft on the rotor, which are used in order to lower mechanical stress on magnets [9] have even lower inductance in comparison to machines with iron shaft, due to high reluctance. The main characteristic of high speed PM machines which cause inductance to be very low is small number of turns. Namely, due to very high rotational speeds and output voltage which is determined by power electronics, number of turns has to be relatively small in comparison with conventional machines.

One of the consequences of such a low inductance is significant current ripple which might be present in stator currents. One of the measures which is used for reduction of ripple in stator current is addition of external inductors in certain applications. However, these inductors cause additional price of the system and may represent additional problem in situations when system needs to be light and portable, like for portable gas turbine power units [8]. Although too low inductance has certain drawbacks, previously mentioned, too high inductance might also represent a limitation because of the stator voltage imposed by inverter. Discussion about trade-offs related to inductance value will be in a full paper.

CONCLUSIONS

The presented paper discusses certain trade-offs related to design of high-speed PM machines, such as stator topology, winding topology and inductance. Full paper will elaborate these issues in more details, as well as some other trade-offs, such as those related to selection of magnet and retaining-sleeve materials.

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